

Temporal variability in early afterglows of short gamma-ray bursts

Zhuo Li,^{1,2★} Z. G. Dai^{1★} and T. Lu^{1★}

¹Department of Astronomy, Nanjing University, Nanjing 210093, China

²Particle Astrophysics Laboratory, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100039, China

Accepted 2003 July 22. Received 2003 July 9; in original form 2003 April 17

ABSTRACT

The shock model has successfully explained the observed behaviours of afterglows from long gamma-ray bursts (GRBs). Here, we use it to investigate the so-called early afterglows from short GRBs, which arise from blast waves that are not decelerated considerably by their surrounding medium. We consider a nearby medium loaded with e^\pm pairs. First, the temporal behaviours show a soft-to-hard spectral evolution, from optical to hard X-ray, and then a usual hard-to-soft evolution after the blast waves begin to decelerate. The light curves show variability and consist of two peaks. The first peak, owing to the pair effect, can be observed in the X-ray, although too faint and too short in the optical. The second peak will be detected easily by *Swift*. We show that detections of the double-peak structure in the light curves of early afterglows are very helpful in determining all the shock parameters of short GRBs, including both the parameters of the relativistic source and the surroundings. Besides, from the requirement that the forward-shock emission in short GRBs should be below the Burst and Transient Source Experiment (BATSE) detection threshold, we give a strong constraint on the shock model parameters. In particular, the initial Lorentz factor of the source is limited to be no more than $\sim 10^3$, and the ambient medium density n is inferred to be low, $n \lesssim 10^{-1} \text{ cm}^{-3}$.

Key words: radiation mechanisms: non-thermal – relativity – gamma-rays: bursts.

1 INTRODUCTION

It is recognized that gamma-ray bursts (GRBs) may be divided into at least two classes: one third of the bursts with short duration ($\lesssim 2$ s) and hard spectra, and the other two thirds with long duration ($\gtrsim 2$ s) and soft spectra (Kouveliotou et al. 1993; Dezalay et al. 1996; Paciesas et al. 2003). The detections of afterglows from long/soft GRBs combined with their redshift measurements have revealed their cosmological origin (see van Paradijs et al. 2000 for a review). Their afterglows are widely believed to come from a blast wave driven by relativistic ejecta into an ambient medium (see reviews of Cheng & Lu 2001; Mészáros 2002). Unfortunately, it is impossible so far for observations to follow short GRBs systematically at longer wavelengths. The effort of searching transient afterglow emission from short/hard GRB usually yields only some upper limits (e.g. Kehoe et al. 2001; Gorosabel et al. 2002; Hurley et al. 2002; Klotz, Boër & Atteia 2002). The difficulty in detecting short GRB afterglow is mainly a result of the poor prompt localization by current satellites for these bursts. This problem is waiting for the upcoming *Swift* satellite to resolve it. Lazzati, Ramirez-Ruiz & Ghisellini (2001) report the discovery of a ~ 30 s delayed, transient and fading

hard X-ray emission in the Burst and Transient Source Experiment (BATSE) light curves of a sample of short GRBs; the soft power-law spectrum and the time evolution are consistent with those predicted by the afterglow model.

Based on the widely accepted blast wave model, Panaitescu, Kumar & Narayan (2001) studied the long-term afterglows of short GRBs coming from the blast waves. In this paper, we focus on the investigation of early afterglow emission, which arises from the blast wave before it transits to the self-similar evolution in the ambient medium (Blandford & McKee 1976). We consider pair loading in the external medium, which is caused by the collision between the outgoing gamma-rays and the scattered photons off the external medium (Dermer & Böttcher 2000; Madau & Thompson 2000; Madau, Blandford & Rees 2000; Thompson & Madau 2000; Mészáros, Ramirez-Ruiz & Rees 2001; Beloborodov 2002; Ramirez-Ruiz, MacFadyen & Lazzati 2002). The pairs will affect the behaviour of early afterglows. As the short GRBs have ~ 20 times less fluence than long GRBs (Mukherjee et al. 1998), the kinetic energy of short GRBs must also be ~ 20 times less than long GRBs, provided that the efficiencies for producing gamma-rays are the same for both classes (Panaitescu & Kumar 2000). We take the typical kinetic energy of short GRBs as 10^{52} ergs here. Furthermore, we assume that the shocks in short GRBs have parameters similar to those of long GRBs, except for the ambient density, which is believed to be lower if short GRBs originate from the compact binary

★E-mail: lizhuo@mail.ihep.ac.cn (ZL); daizigao@public1.ptt.js.cn (ZGD); tlu@nju.edu.cn (TL)

mergers (Eichler et al. 1989; Narayan, Paczyński & Piran 1992). Later on, we will show that low density is required for a short GRB (equation 17 and discussions below). In Section 2, we discuss the hydrodynamics of short GRBs; in Section 3, we discuss pair loading in the external medium. An early afterglow from the blast wave is derived in Section 4. Section 5 gives conclusions and observational implications.

2 HYDRODYNAMICS OF SHORT GRBS

A GRB itself is believed to come from internal shocks which are caused by different Lorentz factors of shells within the ejecta (Rees & Mészáros 1994). After producing GRBs, the ejecta cools down rapidly and may be considered as a cold shell. The interaction between the outgoing shell and ambient medium leads to two shocks: a forward shock propagating into the medium and a reverse shock sweeping up the ejecta matter, with a contact discontinuity separating the shocked ejecta matter and the shocked medium. So the kinetic energy of the ejecta can be dissipated into the internal energy of the medium by the forward shock and into the internal energy of the ejecta matter by the reverse shock. According to Sari (1997), there are two time-scales. One is relevant to the forward shock, at which the shell reaches an deceleration radius where the shell has given the medium an energy comparable to its initial energy,

$$t_{\text{dec}} = 45 E_{k,52}^{1/3} \eta_{300}^{-8/3} n_{-2}^{-1/3} \left(\frac{1+z}{2} \right) \text{s}, \quad (1)$$

where $E_k = 10^{52} E_{k,52}$ erg and $\eta = 300 \eta_{300}$ are the fireball kinetic energy and the initial Lorentz factor, $n = 0.01 n_{-2} \text{ cm}^{-3}$ is the particle density of the ambient medium and z is the redshift of the source. The other is relevant to the reverse shock, at which the reverse shock accelerates to become relativistic. The ratio between the two time-scales is defined as

$$\xi = 12 E_{k,52}^{1/6} \left(\frac{\Delta}{3 \times 10^9 \text{ cm}} \right)^{-1/2} \eta_{300}^{-4/3} n_{-2}^{-1/6}, \quad (2)$$

where Δ is the shell width (in observer frame) of the ejecta. In the internal-shock model, the shell width is $\Delta = cT = 3 \times 10^9 T_{-1} \text{ cm}$, with $T = 0.1 T_{-1} \text{ s}$ the duration of the GRB. Equation (2) shows that ξ is not sensitive to E_k and n , and is only slightly dependent on η , which is not accepted to be quite larger than 10^3 (implied from equation 17 below and also implied from other aspects of GRBs; see, for example, Lazzati, Ghisellini & Celotti 1999; Derishev, Kocharovskiy & Kocharovskiy 2001). Thus, for short GRBs, we usually have $\xi > 1$. In this case, the reverse shock is initially Newtonian and becomes mildly relativistic when it crosses the shell at t_{dec} . Consequently, the shocked medium has most of the initial energy, and the forward shock goes into the self-similar Blandford-McKee evolution (Blandford & McKee 1976).

3 PAIR LOADING IN GRB MEDIUM

The GRB from internal shocks is emitted early, preceding the development of the blast wave. The gamma-ray front interacts with the ambient medium, leading to two processes: Compton scattering and γ - γ absorption of the scattered photons. As a result, the medium is loaded with e^\pm pairs within a loading radius $R_{\text{load}} = 5 \times 10^{15} E_{\gamma,52}^{1/2} \text{ cm}$, where $E_{\gamma} = 10^{52} E_{\gamma,52}$ erg is the isotropically explosive energy in gamma-rays (Beloborodov 2002). Approximately 10^3 pairs per ambient electron can be created when conditions are right, but usually it is much less, $f_0 \equiv N_{\pm}/N(R_{\text{load}}) = 10^2 f_{0,2}$

(Beloborodov 2002). Therefore, the mass of e^\pm pairs ahead of the blast wave is neglected ($f_0 < m_p/m_e$) because it does not affect the dynamics of the blast wave. Besides, the pairs may be pre-accelerated by the gamma-ray front, but the pair energy does not exceed the ejecta kinetic energy. Provided that the medium density is low and the deceleration occurs outside the pre-accelerated radius R_{acc} (Beloborodov 2002), which is smaller than R_{load} , the deceleration time (equation 1) will not be affected (however, note that, as shown by Beloborodov 2002, for dense enough medium, t_{dec} changes whenever deceleration occurs in a pre-accelerated medium, i.e. $R_{\text{dec}} < R_{\text{acc}}$). Typically, the deceleration time is longer than the one at which the blast wave approaches R_{load} ,

$$t_{\text{load}} = \frac{R_{\text{load}}(1+z)}{2\eta^2 c} = 1.7 E_{\gamma,52}^{1/2} \eta_{300}^{-2} \left(\frac{1+z}{2} \right) \text{s}, \quad (3)$$

and the one at which the blast wave crosses a radius, $R_f = f_0^{1/3} R_{\text{load}}$, where the number ratio, f , of the pair to ambient electron number drops to $f = 1$:

$$t_f = 7.9 E_{\gamma,52}^{1/2} \eta_{300}^{-2} f_{0,2}^{1/3} \left(\frac{1+z}{2} \right) \text{s}. \quad (4)$$

Thus, for short GRBs we have the order $t_{\text{load}} < t_f < t_{\text{dec}}$.

Here, when introducing radius R_f , we have assumed mixing of particles in the blast wave that allows the newly added post-shock particles to share energy with earlier injected pairs. Before the reverse shock crosses the ejecta and vanishes at t_{dec} , the existence of the contact discontinuity prevents the earlier pairs from being far downstream from the forward shock front. The total shocked mediums are compressed between the contact discontinuity and the forward shock front. Furthermore, the coupling of leptons with baryons may take place in presence of even weak magnetic fields (e.g. Madau & Thompson 2000; Mészáros et al. 2001); therefore the total particles are possibly mixing, allowing continuous transmission of energy from baryons to leptons. We will take the mixing hypothesis in the following.

4 EARLY AFTERGLOWS OF SHORT GRBS

Now we derive the temporal property of early afterglows from forward shocks of short GRBs. We consider the source as an isotropic explosion, even though it may have jet geometry, because the jet effect is not important at early times when the jet open angle is larger than $\sim 1/\eta$.

4.1 Phase $t_{\text{load}} < t < t_f$

We begin with the blast wave having swept up all the produced pairs at R_{load} . The pairs will modify the usual property of the afterglow, because the same energy will be shared by many more leptons. Furthermore, the pairs will increase the radiation efficiency significantly. With the mixing hypothesis, the comoving-frame random lepton Lorentz factor is

$$\gamma_m = \frac{m_p}{(1+f)m_e} \epsilon_e \eta. \quad (5)$$

Here, $f \equiv N_{\pm}/N_e$, and the energy density in leptons and magnetic field $B^2/4\pi$ behind the shock are usually parameterized by the fractions $\epsilon_e = 0.1 \epsilon_{e,-1}$ and $\epsilon_B = 0.01 \epsilon_{B,-2}$ of the total internal energy density ($\eta^2 n m_p c^2$), respectively. For $f > 1$ at $t_{\text{load}} < t < t_f$, this Lorentz factor is a factor of $(1+f) \approx f$ lower than usual case, and

the corresponding synchrotron frequency is therefore

$$\nu_m = 1.8 \times 10^{14} \epsilon_{e,-1}^2 \epsilon_{B,-2}^{1/2} \eta_{300}^4 n_{-2}^{1/2} f_2^{-2} \left(\frac{1+z}{2} \right)^{-1} \text{ Hz}, \quad (6)$$

which is in the optical band if $f = f_0 = 10^2 f_{0,2}$ at t_{load} , as opposed to the hard X-ray of the usual case. Now the pair number dominates the ambient electron number, the total lepton number is $N_{\text{lep}} \simeq \frac{4}{3} \pi R_{\text{load}}^3 n f_0$. The peak spectral power (in comoving frame) per lepton is $P_{v,\text{max}} = 1.4 \times 10^{-22} B \text{ erg s}^{-1} \text{ Hz}^{-1}$. We then have the afterglow peak flux

$$F_p = N_{\text{lep}} \eta P_{v,\text{max}} \frac{(1+z)}{4\pi d_1^2} \\ = 3.2 \epsilon_{B,-2}^{1/2} E_{k,52}^{3/2} \eta_{300}^2 n_{-2}^{3/2} f_{0,2} d_{1,28}^{-2} \left(\frac{1+z}{2} \right) \mu\text{Jy} \quad (7)$$

where $d_1 = 10^{28} d_{1,28}$ is the GRB's luminosity distance. To calculate the synchrotron spectrum, we still need to know the cooling frequency that is corresponding to those leptons which cool by synchrotron-Paradijs inverse-Compton radiation in a dynamical time t , i.e.

$$\nu_C = 2.5 \times 10^{20} \epsilon_{B,-2}^{-3/2} \eta_{300}^{-4} n_{-2}^{-3/2} t^{-2} \left(\frac{1+Y}{2} \right)^{-2} \left(\frac{1+z}{2} \right) \text{ Hz}, \quad (8)$$

where Y is the Compton parameter. According to Panaitescu & Kumar (2000), $Y = (1/2)\{[(5/6)(\epsilon_e/\epsilon_B) + 1]^{1/2} - 1\} \approx 1$. Now, for observer's time $t = t_{\text{load}}$,

$$\nu_C(t_{\text{load}}) = 3.4 \times 10^{20} \epsilon_{B,-2}^{-3/2} E_{\gamma,52}^{-1} n_{-2}^{-3/2} \left(\frac{1+z}{2} \right)^{-1} \text{ Hz}. \quad (9)$$

The synchrotron spectrum from leptons distributed as $dN_{\text{lep}}/d\gamma_e \propto \gamma_e^{-p} (\gamma_e > \gamma_m)$ is a broken power-law with break frequencies ν_m and ν_C : $F_\nu \propto \nu^{1/3}$ at $\nu < \nu_p \equiv \min(\nu_m, \nu_C)$; $F_\nu \propto \nu^{-1/2}$ for $\nu_C < \nu < \nu_m$ or $F_\nu \propto \nu^{-(p-1)/2}$ for $\nu_m < \nu < \nu_C$; and $F_\nu \propto \nu^{-p/2}$ at $\nu > \max(\nu_m, \nu_C)$ (Sari, Piran & Narayan 1998). Here, we neglect the synchrotron self-absorption, which is only important at longer wavelengths – for example, radio or infrared.

Because $f \propto N_e^{-1} \propto R^{-3} \propto t^{-3}$, equation (6) implies that the peak frequency increases rapidly – as $\nu_m \propto t^6$ – from the optical to the hard X-ray band eventually (equation 13). Thus, we have the following scaling laws for $t_{\text{load}} < t < t_f$:

$$F_p = \text{const.}, \quad \nu_m \propto t^6, \quad \nu_C \propto t^{-2} \quad (t_{\text{load}} < t < t_f). \quad (10)$$

The afterglow shows a soft-to-hard spectral evolution during this phase. Observed at a fixed frequency, ν_{ob} , between the optical and hard X-ray, the light curve will show a rapid increase, $F_\nu \propto t^{3(p-1)}$, and then a sharp decreasing, $F_\nu \propto t^{-2}$, after ν_m crosses ν_{ob} at

$$t_{\text{pk}} = 4.9 \frac{\nu_{\text{ob},17}^{1/6} E_{\gamma,52}^{1/2} f_{0,2}^{1/3}}{\epsilon_{e,-1}^{1/3} (\epsilon_{B,-2} n_{-2})^{1/12} \eta_{300}^{8/3}} \left(\frac{1+z}{2} \right)^{7/6} \text{ s}. \quad (11)$$

4.2 Phase $t_f < t < t_{\text{dec}}$

Outside R_f , we have $f < 1$, implying that the pair effect is negligible. Then the afterglow property approaches the usual case, where

$$F_p \propto N_e \propto t^3, \quad \nu_m = \text{const.}, \quad \nu_C \propto t^{-2} \quad (t_f < t < t_{\text{dec}}). \quad (12)$$

In detail,

$$\nu_m = 1.8 \times 10^{18} \epsilon_{e,-1}^2 \epsilon_{B,-2}^{1/2} E_{k,52} \eta_{300}^4 n_{-2}^{1/2} \left(\frac{1+z}{2} \right)^{-1} \text{ Hz} \quad (13)$$

is a constant and should be in the hard X-ray band. The cooling frequency continues to decrease (equation 8) to

$$\nu_C(t_{\text{dec}}) = 5.0 \times 10^{17} \epsilon_{B,-2}^{-3/2} E_{k,52}^{-2/3} \eta_{300}^{4/3} n_{-2}^{-5/6} \left(\frac{1+z}{2} \right)^{-1} \text{ Hz} \quad (14)$$

at $t = t_{\text{dec}}$. Note that $\nu_m > \nu_C(t_{\text{dec}})$, implying that ν_C has crossed ν_m at a certain moment t_{cm} after which the spectrum peaks at ν_C , which is in X-ray. Owing to ambient electrons being picked up, the peak flux increases rapidly to

$$F_p(t_{\text{dec}}) = 580 \epsilon_{B,-2}^{1/2} E_{k,52} n_{-2}^{1/2} d_{1,28}^{-2} \left(\frac{1+z}{2} \right) \mu\text{Jy} \quad (15)$$

at $t = t_{\text{dec}}$. If observing at a fixed sub-keV frequency, we can see in this phase the light curve climbing up again.

Now a constraint on short GRBs arises from the requirement that the flux in sub-MeV should not exceed the BATSE detection threshold. Otherwise, as $t_{\text{dec}} > 2$ s, the burst is not short any more. With $n = 0.01$ and other parameters in their typical value, we obtain the flux given by

$$\Phi(\text{MeV}) \simeq 2\nu_m F_{\nu_m} = 2(\nu_m \nu_C)^{1/2} F_p = 1.1 \times 10^{-8} \\ \times \epsilon_{e,-1} E_{k,52}^{2/3} \eta_{300}^{8/3} n_{-2}^{1/3} d_{1,28}^{-2} \text{ erg cm}^{-2} \text{ s}^{-1}. \quad (16)$$

We set that the BATSE threshold is $1 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$, leading to a constraint on the 'short GRB' parameters of

$$\epsilon_{e,-1} E_{k,52}^{2/3} \eta_{300}^{8/3} n_{-2}^{1/3} d_{1,28}^{-2} < 1. \quad (17)$$

Note that the most stringent constraint is on η , which is not allowed to be too large, i.e. $\eta \lesssim 10^3$. A lower limit to η arises from the requirement that during the prompt sub-MeV burst, the optical depth owing to scattering off fireball electrons, $\tau_b = \sigma_T N_b / 4\pi R_\gamma^2$, should be less than unity (Rees & Mészáros 1994), with $N_b = E_k / \eta m_p c^2$ the fireball baryon number, $R_\gamma \leq \eta^2 c \delta t$ the radius at which the fireball kinetic energy dissipated to gamma rays, and δt the shortest time-scale of rapid variability in the GRB profile. This leads to $\eta > 330 E_{k,52}^{1/5} \delta t_{-2}^{-2/5}$, thus the η value taken in equation (17) is to the lower limit. If the other parameters are fixed to their typical values, the ambient density for short GRBs is limited to $n \lesssim 0.01 \text{ cm}^{-3}$ (equation 17), consistent with the clean-environment hypothesis to short GRB models of compact binary systems, e.g. Eichler et al. (1989) and Narayan et al. (1992).

4.3 Phase $t > t_{\text{dec}}$

In this phase, the blast wave begins to decelerate considerably. If the electrons obtain a significant fraction of total energy, $\epsilon_e \sim 1$, the blast wave will evolve in the radiative regime, because all the electrons are fast cooling, with $\nu_C < \nu_m$. The light curve is somewhat complicated in this case, with the light-curve index related to ϵ_e (Böttcher & Dermer 2000; Li, Dai & Lu 2002). For the typical value $\epsilon_e = 0.1$, we can safely consider a adiabatic blast wave, so the well know scaling laws are:

$$F_p = \text{const.}, \quad \nu_m \propto t^{-3/2}, \quad \nu_C \propto t^{-1/2} \quad (t > t_{\text{dec}}), \quad (18)$$

where F_p is given by equation (15). The afterglow spectrum shows the usual hard-to-soft evolution after t_{dec} . Observed at a certain frequency ν_{ob} between the optical and keV band, when ν_m or ν_C crosses ν_{ob} (whichever happens first), the observed flux reaches a peak with $F_{\text{ob}} = F_p \simeq 580 \mu\text{Jy}$. It is a magnitude $\simeq 15.6$ if observed in the optical. Thus, there is another peak in the light curve other than the first one in the phase $t < t_f$. Furthermore,

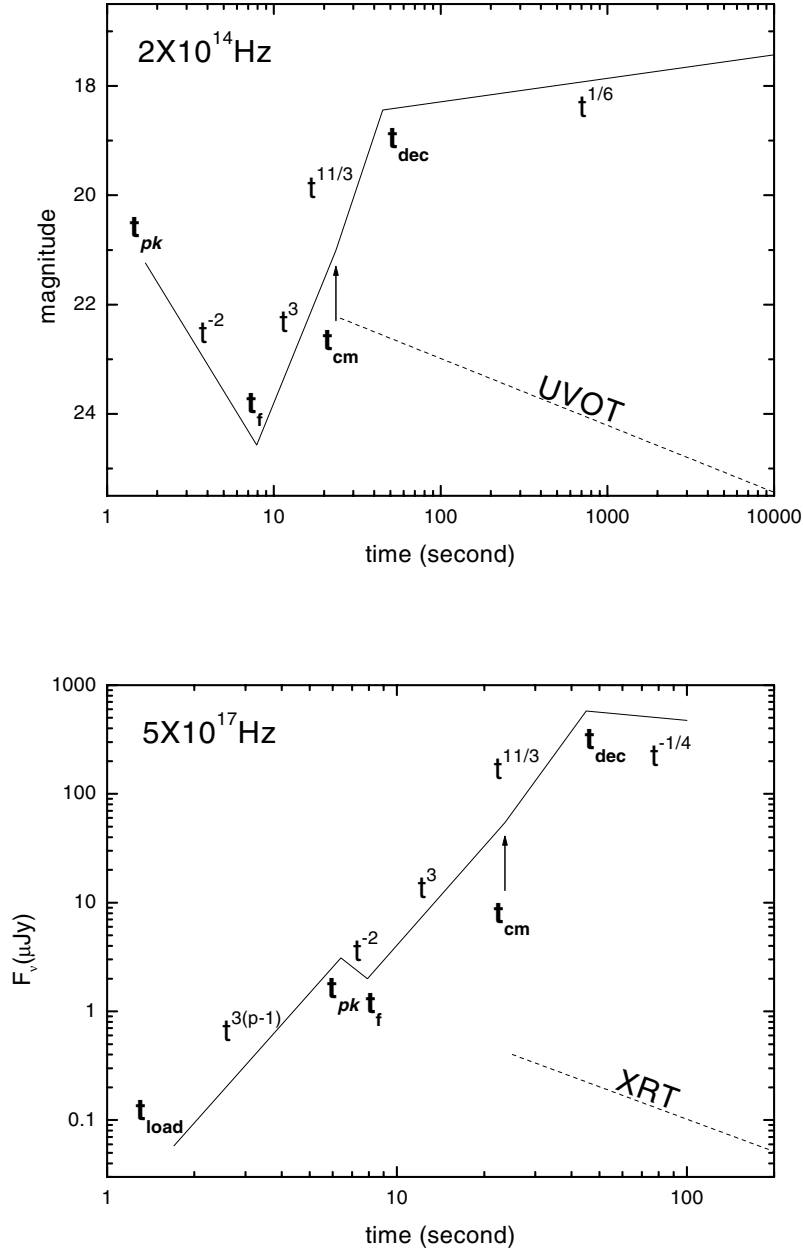


Figure 1. Example of early afterglows of short GRBs at two fixed frequencies, $\nu = 2 \times 10^{14}$ and 5×10^{17} Hz (upper and bottom frames, respectively). The parameter values taken to calculate the light curves are: $E_\gamma = E_k = 10^{52}$ erg, $n = 0.01 \text{ cm}^{-3}$, $f_0 = 10^2$, $p = 2$ and the others are equal to typical values of long GRBs (see text for details). The characteristic times and the scaling laws of fluxes with time are marked. The dashed lines show the sensitivity of *Swift* instruments, the X-ray (XRT) and ultraviolet optical (UVOT) telescopes.

this second peak is much stronger than the first one. Lazzati et al. (2001) claim to have detected such a delayed hard X-ray peak.

In Fig. 1, we show the light curves at two bands, the optical and the X-ray; also labelled in this figure are the characteristic times and the light-curve scaling laws.

5 CONCLUSION AND DISCUSSION

Based on the shock model which has been essentially successful to explain long GRB afterglows, we derive here the light curves of short GRB afterglows in the early phase when the blast wave is

not decelerated by the ambient medium considerably. The reverse-shock emission has been ignored from the beginning because it is always Newtonian initially for short GRBs. We consider the pair-loading effects on the emission. The spectrum shows rapid soft-to-hard evolution over the first several seconds ($t < t_f$), and then a usual hard-to-soft evolution after several tens of seconds ($t > t_{dec}$). Simultaneously, there are two peaks appearing in the light curves in the optical to hard X-ray range. The first ‘pair peak’ will appear at the optical, but it is too faint (mag ~ 21) and too short (~ 2 s) to be detected by any current and upcoming instrument. But the double-peak structure in the light curve is expected to be observed at the X-ray band: the first peak at t_{pk} and the second peak at around t_{dec} . It took only 20 to 70 s for *Swift* to point its Narrow Fields

instruments, consisting of X-ray and ultraviolet optical telescopes, to the GRB direction; short GRBs will be detected easily before the second peak (Fig. 1). The recently proposed microsatellite *ECLAIR* (Barret 2003) is even expected to be capable of detecting the first peak.

Though the reverse shock becomes mildly relativistic finally at t_{dec} , we have neglected its emission here, which is mainly in the soft band – the optical, say. If we consider further the effect of pair-loading in the fireball which results from γ – γ absorption of the prompt burst in the fireball, it would be in a much softer band, such as in the infrared. Because the same energy may be shared by more of the produced e^\pm pairs, the lower-energy leptons would radiate at softer frequency. So the reverse-shock emission will not affect the X-ray light-curve, although it may affect the optical one.

The blast wave emission in sub-MeV must be under the BATSE detection threshold for short GRBs. Provided that the energy is $E_k = 10^{52}$ erg, and $\epsilon_{e,-1} = d_{1,28} = 1$, similar to typical values of long GRBs, we find a constraint on the initial Lorentz factor and the ambient density of $\eta_{300}^{8/3} n_{-2}^{1/3} < 1$ (cf. equation 17), and that the Lorentz factor of short GRBs is not allowed to be large, i.e. $\eta < 10^3$. This also limits the ambient density to $n \lesssim 0.1 \text{ cm}^{-3}$, which is consistent with the upper limit on late-time short GRB afterglows. So far, the best constraint on short GRB afterglows comes from the observation of short/hard GRB 020531, which yields the following limiting magnitudes in R band: 18.5 at 88 min and 25.2 at 2.97 d (Klotz et al. 2002). Under a standard afterglow model, these data do not allow for a dense medium, i.e. $n \lesssim 0.1 \text{ cm}^{-3}$ (see fig. 2 in Panaitescu et al. 2001). Low densities favour the GRB model related to compact object mergers (Eichler et al. 1989; Narayan, Piran & Paczyński 1992) in galactic haloes or in the intergalactic medium.

At $t_{\text{load}} (> 2 \text{ s})$, the optical photons in the pulse may be up-scattered to MeV by a synchrotron self-Compton process. But the flux is of orders lower than the BATSE detection threshold and is unable to change the short-duration property of short GRBs.

Unlike the long GRBs which may overlap the early afterglows and lead to complication, the short GRBs stop abruptly. In addition, owing to lower ambient density, the blast waves take a longer time to begin decelerating considerably, so their early afterglows are observed easily. If detected and confirmed, the double-peak structure in early afterglows has an important indication for short GRBs – with the redshift having been measured, we can determine the most important parameter η from equations (4) and (11) (Beloborodov 2002), and then we can use the value of η further to constrain the other parameters, E_k and n , using equation (1). So an observation of early afterglows provides important constraints on the short GRB parameters, related both to the relativistic flow and to the surroundings.

ACKNOWLEDGMENTS

We would like to thank the referee for valuable comments. ZL thanks X. Y. Wang for valuable discussions and R. F. Shen for careful reading. This work was supported by the National Natural Science Foundation of China, the National 973 Project (NKBRSG19990754) and the Special Funds for Major State Basic Research Projects.

REFERENCES

- Barret D., 2003, in Ricker G. R., Vanderspek R. K., eds, AIP Conf. Proc. 662, Gamma-Ray Burst and Afterglow Astronomy 2001. Am. Inst. Phys., New York, p. 481
- Beloborodov A. M., 2002, ApJ, 565, 808
- Blandford R. D., McKee C. F., 1976, Phys. Fluids, 19, 1130
- Böttcher M., Dermer C. D., 2000, ApJ, 532, 281
- Cheng K. S., Lu T., 2001, Chin. J. Astron. Astrophys., 1, 1
- Derishev E. V., Kocharovskiy V. V., Kocharovskiy V. V., 2001, A&A, 372, 1071
- Dermer C., Böttcher M., 2000, ApJ, 534, L155
- Dezalay J. P., Lestrade J. P., Barat C., Talon R., Sunyaev R., Terekhov O., Kuznetsov A., 1996, ApJ, 471, L27
- Eichler D., Livio M., Piran T., Schramm D. N., 1989, Nat, 340, 126
- Gorosabel J. et al., 2002, A&A, 383, 112
- Hurley K. et al., 2002, ApJ, 567, 447
- Kehoe R. et al., 2001, ApJ, 554, L159
- Klotz A., Boër M., Atteia J. L., 2002, A&A, 404, 815
- Kouveliotou C., Meegan C. A., Fishman G. J., Bhat N. P., Briggs M. S., Koshut T. M., Paciesas W. S., Pandleton G. N., 1993, ApJ, 413, L101
- Lazzati D., Ghisellini G., Celotti A., 1999, MNRAS, 309, L13
- Lazzati D., Ramirez-Ruiz E., Ghisellini G., 2001, A&A, 379, L39
- Li Z., Dai Z. G., Lu T., 2002, MNRAS, 330, 955
- Madau P., Thompson C., 2000, ApJ, 534, 239
- Madau P., Blandford R., Rees M. J., 2000, ApJ, 541, 712
- Mészáros P., 2002, ARA&A, 40, 137
- Mészáros P., Ramirez-Ruiz E., Rees M. J., 2001, ApJ, 554, 660
- Mukherjee S., Feigelson E. D., Jogesh Babu G., Murtagh F., Fraley C., Raftery A., 1998, ApJ, 508, 314
- Narayan R., Paczyński B., Piran T., 1992, ApJ, 395, L83
- Paciesas W. S., Briggs M. S., Preece R. D., Mallozzi R. S., 2003, in Ricker G. R., Vanderspek R. K., eds, AIP Conf. Proc. 662, Gamma-Ray Burst and Afterglow Astronomy 2001. Am. Inst. Phys., New York, p. 248
- Panaitescu A., Kumar P., 2000, ApJ, 543, 66
- Panaitescu A., Kumar P., Narayan R., 2001, ApJ, 561, L171
- Ramirez-Ruiz E., MacFadyen A. I., Lazzati D., 2002, MNRAS, 331, 197
- Rees M. J., Mészáros P., 1994, ApJ, 430, L93
- Sari R., 1997, ApJ, 489, L37
- Sari R., Piran T., Narayan R., 1998, ApJ, 497, L17
- Thompson C., Madau P., 2000, ApJ, 538, 105
- van Paradijs J., Kouveliotou C., Wijers R. A. M. J., 2000, ARA&A, 38, 379

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.